Detect3D Validation Report

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Foreword

Detect3D, developed by Insight Numerics, was released in 2013 in response to an industry demand for Fire and Gas (F&G) Mapping studies to be performed using updated 3D methodologies directly within project CAD files. Prior to its release, F&G Mapping was only available as a service through specialist consultancies, whose in-house software operated as a "black box" technology. The results produced by the consultancies were accepted as-is, as no verification or validation data was made available to the client or existed in the public domain. This situation was extremely atypical in the technical safety industry, where validation of software is commonly a requirement before it is deployed on a project. Several technologies used in the field, in particular Computational Fluid Dynamics (CFD) software, went through extensive validation procedures before being used by engineers to model gas dispersions, fires and explosions. The same critical validation requirement, oddly, has consistently not been required of F&G mapping software.

Insight Numerics is committed to reversing this situation, and this validation report is a product of the company's commitment to transparency regarding the algorithms used in Detect3D. The importance of a validation process is not only confidence in the results, but also the knowledge of when to proceed with caution, and anticipate that a higher degree of accuracy is required of a particular situation.

All of the data produced in this report is freely available to the public, so that engineers can verify the results independently. The data is available from the following link:

https://dl.dropboxusercontent.com/u/110049730/Public%20Data.zip

If the reader has any questions or comments about this document, please email the authors directly (email addresses given on the cover page).

Summary and Recommendations

A series of test cases have been defined for the fire and gas mapping software Detect3D. In all cases, the coverage given by Detect3D has been compared to hand calculations, or numerical calculations. The pass/fail criteria has been set to 1% absolute error for coverage.

The default settings in Detect3D of 0.25 meters for zone spacing, and 1° resolution with 2 adaptive refinements for flame detectors, have been shown to be highly accurate, calculating coverage within 1% absolute error for all cases tested.

These conclusions are limited only to the test cases in the report. Sensitivity studies for the zone resolution and flame detector ray casting resolution should always be carried out for projects using Detect3D.

Introduction

There is no generally accepted theory addressing the calculation of coverage of fire and gas detectors. Each method, whether that be an in-house solution or a software product such as Detect3D, contains unique algorithms devised by engineers to solve the various problems associated with the coverage calculation. Detect3D itself contains many novel algorithms that are new to F&G mapping. These algorithms require testing to ensure their accuracy due to the nature of the software's deployment on facilities that have multiple hazardous environments. This report documents the validation of these algorithms.

Validation or Verification?

The cases discussed in this report are purely numerical – no physical experiments were carried out. This decision was intentional, as the calculation of coverage is a geometric, purely numerical problem with a numerical solution. No predictions about the physical world are made at any point during a F&G mapping project; physical properties, such as the size of the fire, the response of the detector to that fire, and the size of the gas cloud, are all determined prior to the study being performed. On occasion, models representing the physical reality may be used to inform these decisions. For example, CFD or PHAST may be used to calculate fire sizes or gas cloud sizes which are then input into the F&G mapping study, and are not a product of the F&G mapping study itself.

The validation study contained herein may therefore be categorized as "numerical validation" of a series of geometrical operations and algorithms devised by Insight Numerics and deployed in Detect3D. Note that this does *not* imply that the cases are verification rather than validation. Verification concerns the correct implementation of known algorithms, and may not require the running of the computer code at all. This exercise, on the other hand, tests the accuracy of the algorithms and does require the algorithm's code to be run or executed. The testing in this report is therefore considered a validation exercise.

Difference between Coverage and Detection

The claim that no physical predictions are performed in Detect3D may be surprising. After all, a person may consider the likelihood of detecting a fire or gas leak to be a physical property of the detector layout. While that is true, there is an important difference between detection rate and detector coverage – the two are *not* synonymous. A layout of 90% coverage could have a detection rate of 95%, or a detection rate of 80%, depending on several factors. This is particularly true to gas mapping studies, where the coverage calculation tends to be conservative relative to detection rate if in an enclosed environment. In naturally ventilated conditions, the opposite is true.

The reason for the difference is that detection rate depends greatly on the specifics of each event. Take, for example, a fire that is partially obscured by a rack of small diameter pipes, such that the fire is easily visible to a flame detector through the pipes. Based on current flame detector technology, if the pipes are obstructing the base of the flame there is every chance that the detector will go into alarm, whereas if the pipes are obstructing the flickering part of the flame, there is a high likelihood that the detector will not alarm. The reason for this is that flame detectors typically consider both radiation input *and* flicker. The balance of these inputs varies greatly with manufacturer, model, detector type, fire, and other factors. Given these factors, it is impractical to expect that any person can predict response or detection rate without knowing the (proprietary) details of the specific detector's internal algorithms.

Coverage, on the other hand, is relatively easy to calculate, and is independent of the internal workings of the detector. It is due to the accessibility of coverage, and the vagaries of detection rate, that fire safety engineers use coverage as the metric to assess the effectiveness of detector layouts. It is important to keep in mind that that coverage it is *not* a prediction of detection rate, even though it may be closely correlated to detection rate in most cases. The crucial difference between coverage and detection is that coverage is somewhat abstract from the physical world, while detection exists directly within it. Since coverage is the property calculated by Detect3D, no physical validation is required.

Methodology

Case Definition

Test cases have been defined for flame detector mapping, gas detector mapping, and the internal volume calculation. Dimensions of objects and zones used in these cases have been chosen to represent typical dimensions on projects, erring on the side of conservatism where appropriate.

In all cases, the 1ooN and 2ooN coverage was noted and compared to hand calculations or numerical calculations using the solid modeling software Rhino. Zone spacing, and ray spacing for flame detector studies, were adjusted with the absolute error in coverage recorded at each setting.

Software Version

All test cases have been carried out using Detect3D Version 1.60.

Common Factors that Affect Accuracy

Zone Spacing

The volume of the zone is discretized by an evenly-spaced point cloud. Coverage is calculated at each point, and the coverage statistics are derived simply by summing the total number of points at a specific coverage level and dividing by the total number of points (rather, the total number of *external* points i.e. not within equipment volume).

The accuracy of the coverage calculations is affected most strongly by the spacing of the point cloud. The appropriate spacing should take account of factors such as the ray casting accuracy, size of geometry, and many other factors. It should be expected that the accuracy of the calculation increases as the point cloud spacing decreases to zero, meaning that the coverage calculation would be exact if spacing was infinitely small. In many cases, the error associated with zone spacing tends towards conservatism. This is almost always true for gas mapping and the external point calculation whereas flame detector mapping is complicated by interaction of the zone with the ray casting.

The default spacing for the point cloud in Detect3D is 0.25 meters, and is labeled as 'Coarse' in the software. The focus of the validation has been 0.25 meter spacing and smaller.

Exact Point Alignment

In rare circumstances, points can lie *exactly* on the boundary of the zone. Most commonly this occurs during the internal volume calculation, where a box has been added to the geometry with the exact coordinates required for many of the points to lie on the surface of the box. In that case, whether the points are internal or external is a matter of the floating point accuracy of the calculations. This can lead to unusual behavior and slightly larger errors in the internal volume calculation than those reported here. To fix this the zone can be moved by 1 mm in the x, y, and z direction. This will not affect the overall project, but it will resolve the alignment error.

Ray Casting Resolution

Ray casting resolution is adjusted in two ways – the initial ray mesh, which casts rays at a certain angular resolution, and the number of adaptive refinements, which casts additional rays where geometry has been detected by the initial set of casted rays. As seen in the results provided in this report the coverage results for flame detection are remarkably robust. However, care should always be taken to perform sensitivity studies for all Detect3D projects.

Flame Detection

Case 01: Single Unobstructed FOV

Summary

This case tests the ability of Detect3D to calculate the 1ooN coverage of a single unobstructed field-of-view (FOV) which is fully enclosed within a zone. Multiple FOV types were tested, and the variance of accuracy with ray spacing and point cloud spacing was tested.

The results show that the 1ooN coverage was calculated within the acceptable 1% error margin. To exceed the 1% error and a point cloud spacing of 0.5 meters is required. Ray spacing has little to no effect on error for this case.

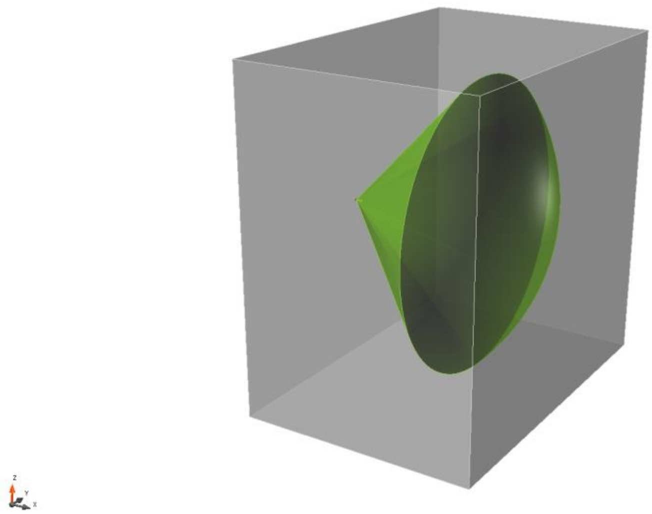

Figure 1: Test case showing a symmetric unobstructed FOV with a 90° cone of vision inside a cuboid zone.

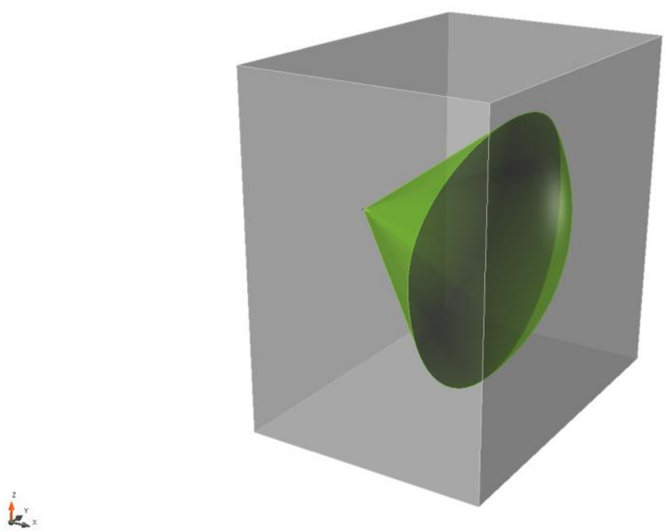

Figure 2: Test case showing an unobstructed FOV with a 35° up angle inside a cuboid zone.

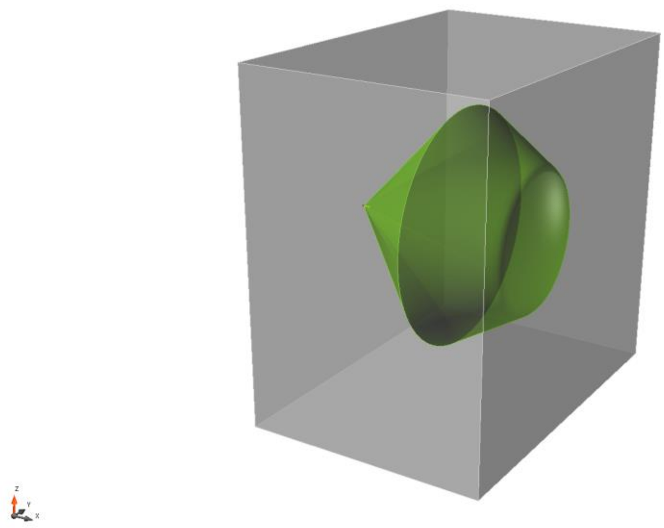

Figure 3: Test case showing an unobstructed FOV with a straight bezel inside a cuboid zone. As opposed to the Bezier curve FOV shown in Figure 1 and 2.

Public File Locations

…/Flame Detector Mapping/Case 01 – Single Unobstructed FOV

Pass / Fail Criteria

1% error margin compared to hand calculations, at 1 degree ray spacing or less, and 0.25 meter point spacing or less.

Results and Discussion

(a) Symmetric – No Bezel

A simplified flame detector FOV is a rounded cone. The profile shown below can be integrated in spherical coordinates to find the internal volume using Eq. 1, where r is the radius of the sphere, ϕ is the angle of the cone, and θ is the angle of revolution.

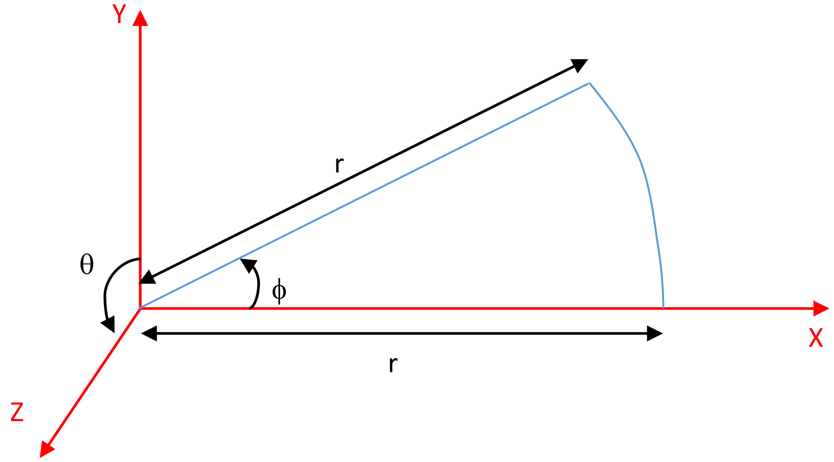

Figure 4: Profile of the simplified flame detector FOV.

$$V_{rounded\ cone} = \int_0^{\theta}\int_0^{\phi}\int_0^{r} r^2 \sin(\phi)\, dr\, d\phi\, d\theta \qquad \textit{Eq. 1}$$

The 1ooN coverage is the volume of the rounded cone divided by the volume of the cuboid zone:

$$1ooN = \frac{V_{rounded\ cone}}{V_{zone}} \qquad \textit{Eq. 2}$$

In the test case, r = 30 meters, ϕ = 45°, and θ = 360° while the zone is a cuboid with side lengths of 35, 50, 50 meters in the x, y, and z directions, respectively. This results in a 1ooN coverage of **18.93%**. The Detect3D results with varying zone spacing's are shown below.

Zone Spacing, m	1ooN	Error
1	17.63%	-1.30%
0.5	18.24%	-0.69%
0.25	18.61%	-0.32%
0.125	18.78%	-0.15%

Ray Spacing, degrees	1ooN	Error
2	18.61%	-0.32%
1	18.61%	-0.32%
0.5	18.61%	-0.32%
0.25	18.61%	-0.32%

(b) 35° Up-Angle – No Bezel

An unsymmetrical flame detector with an up angle of 35° has a profile as shown below. The transition between the vertical and horizontal angles is linear resulting in Eq. 3, where the cone angle, ϕ, is dependent on the angle of revolution, θ.

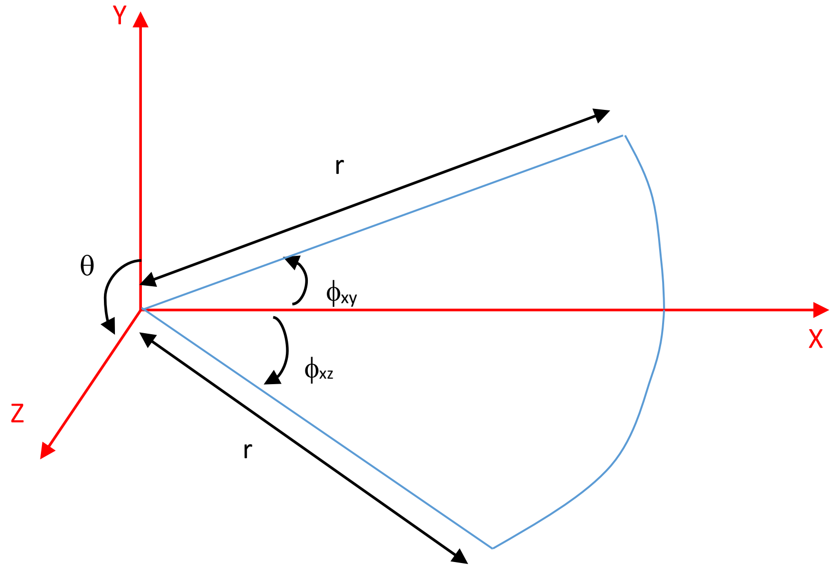

Figure 5: Profile of FOV with different up & horizontal angles.

To calculate the internal volume, the top and bottom halves of the FOV are separated and added in Eq. 4.

$$\phi(\theta) = \left(\frac{\phi_{xz} - \phi_{xy}}{\frac{\pi}{2}}\right)\theta + \phi_{xy} \qquad \textit{Eq. 3}$$

$$V_{FOV} = \int_0^{\theta/2}\int_0^{\phi(\theta)}\int_0^{r} r^2 \sin(\phi)\, dr\ \ d\phi\ d\theta + \int_0^{\theta/2}\int_0^{\phi_{xz}}\int_0^{r} r^2 \sin(\phi)\, dr\ d\phi\ d\theta \qquad \textit{Eq. 4}$$

In the test case, r = 30 meters, ϕxy = 45°, ϕxz = 35°, θ = 360° and the zone is a 35 by 50 by 50 meter cuboid. This results in a 1ooN coverage of **17.06%**. The Detect3D results and error is shown below.

Zone Spacing, m	1ooN	Error
1	15.75%	-1.31%
0.5	16.30%	-0.76%
0.25	16.61%	-0.45%
0.125	16.76%	-0.30%

Ray Spacing, degrees	1ooN	Error
2	16.61%	-0.45%
1	16.61%	-0.45%
0.5	16.61%	-0.45%
0.25	16.61%	-0.45%

(c) Symmetric – Straight Bezel

A flame detector with a straight bezel is shown below. The bezel is linear from a percentage of the max range (edge efficiency) to the full angle of the FOV. The internal volume calculation is separated into two parts: up to the full angle, from the full angle to the effective angle.

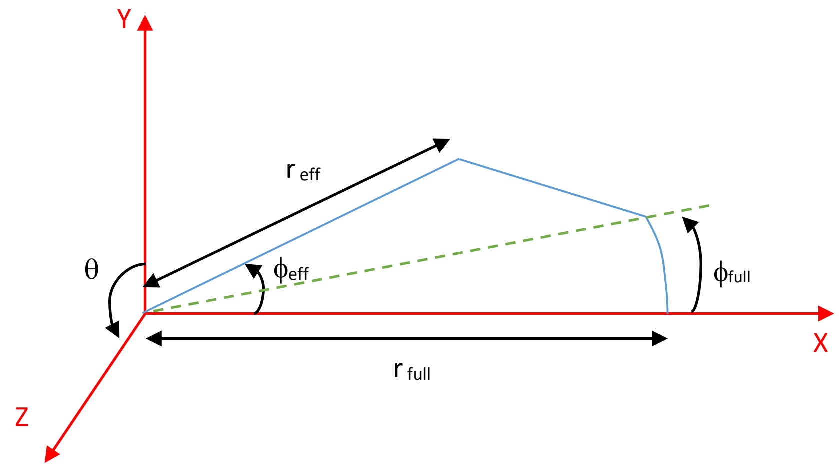

Figure 6: Profile of symmetric FOV with straight bezel.

For the bezel region, the max range is linearly scaled based on effective angle shown by Eq. 5 below.

$$r(\phi) = \left(\frac{r_{eff} - r_{full}}{r_{eff} - r_{full}}\right)\phi + \left(\frac{r_{eff} - r_{full}}{r_{eff} - r_{full}}\right)(-\phi_{full}) + r_{eff} \qquad \textit{Eq. 5}$$

$$\begin{aligned} V_{straight\ bezel} = & \int_0^{\theta}\int_0^{\phi_{full}}\int_0^{r_{full}} r^2 \sin(\phi)\, dr\, d\phi\, d\theta \\ & + \int_{\phi_{full}}^{\phi_{eff}}\int_0^{r(\phi)}\int_0^{\theta} r^2 \sin(\phi)\, d\theta\, dr\, d\phi \end{aligned} \qquad \textit{Eq. 6}$$

For the test case, r $_{eff}$ = 24 meters (Edge Efficiency = 80%), r $_{full}$ = 30 meters, ϕ_{eff} = 45°, ϕ_{full} = 20°, and θ = 360°. These parameters result in a 1ooN coverage of **14.57%**. The coverages given by Detect3D and respective errors are shown in the tables below.

Spacing, m	1ooN	Error
1	12.87%	-1.70%
0.5	13.33%	-1.24%
0.25	13.58%	-0.99%
0.125	13.70%	-0.87%

Ray Spacing, degrees	1ooN	Error
2	13.58%	-0.99%
1	13.58%	-0.99%
0.5	13.58%	-0.99%
0.25	13.58%	-0.99%

The results indicate that less than 1% absolute error has been achieved for coarse zone spacing of 0.25 to 2.0 with respect to the FOV scale. In addition, the error tends to conservatism – the 1ooN coverage results are less than the exact result in all cases. The error also tends towards zero as the zone spacing is reduced, as expected. In an unobstructed case, ray spacing tends to have little effect on error.

Conclusions

The 1ooN coverage for the single point detector case is below 1% absolute error for all cases tested with zone spacing under 0.25 meters and ray spacing under 1 degree. The software has therefore PASSED the test.

Case 02: Single Unobstructed FOV, Rotated

Summary

This case tests Detect3D's accuracy of a FOV rotated via azimuth and declination. A single, symmetric FOV will be rotated within a cuboid zone with a zone spacing of 0.5 and 0.25 meters (from case 01) and ray spacing of 1°.

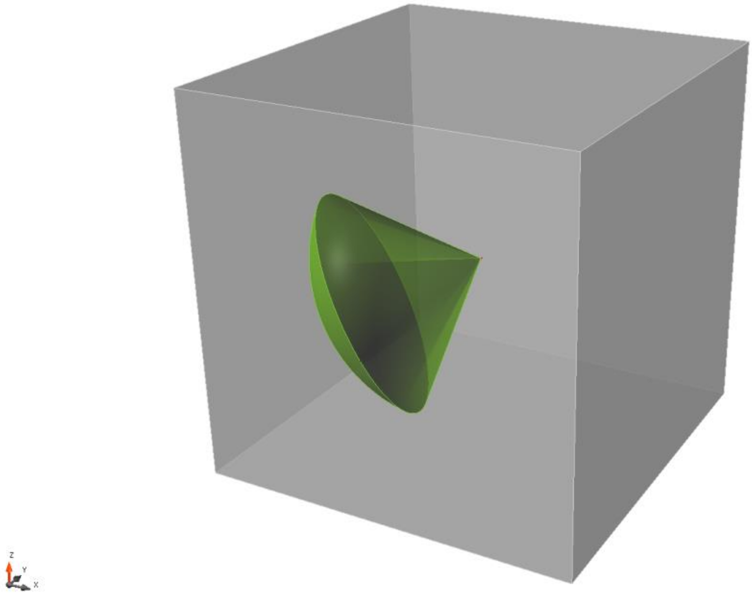

Figure 7: Test case showing a rotated unobstructed FOV inside a cube zone.

The results show that changing azimuth and declination has negligible effect on the accuracy of coverage.

Public File Locations

…/Flame Detector Mapping/Case 02 – Single Unobstructed FOV Rotated

Pass / Fail Criteria

1% Error margin compared to precise hand calculations, at 1 degree ray spacing or less, and 0.25 meter point spacing or less, and less than 0.5% deviation between rotated FOVs.

Results and Discussion

As discussed in the previous case, the volume of a symmetric sphere-capped cone is given by Eq. 7 and the 1ooN coverage is given by Eq. 8.

$$V_{rounded\ cone} = \int_0^{\theta} \int_0^{\phi} \int_0^{r} r^2 \sin(\phi)\, dr\, d\phi\, d\theta \qquad \text{Eq. 7}$$

$$1ooN = \frac{V_{rounded\ cone}}{V_{zone}} \quad \textit{Eq. 8}$$

In this test case, r = 30 meters, ϕ = 45°, and θ = 360° while the zone is a cuboid with side lengths of [70, 70, 70] meters. This results in a 1ooN coverage of **4.83%**. The Detect3D results with zone spacing of both 0.5 and 0.25 meters are shown below, respectively.

[Azimuth, Declination], degrees	1ooN	Error
[25,10]	4.73%	-0.10%
[85,35]	4.73%	-0.10%
[140,65]	4.73%	-0.10%
[175,15]	4.73%	-0.10%
[225,85]	4.73%	-0.10%
[310,-20]	4.73%	-0.10%
[335,-50]	4.73%	-0.10%

[Azimuth, Declination], degrees	1ooN	Error
[25,10]	4.78%	-0.05%
[85,35]	4.78%	-0.05%
[140,65]	4.78%	-0.05%
[175,15]	4.78%	-0.05%
[225,85]	4.78%	-0.05%
[310,-20]	4.78%	-0.05%
[335,-50]	4.78%	-0.05%

The results indicate that less than 1% absolute error has been achieved for both 0.5 and 0.25 zone spacing. Rotation of azimuth and declination of an unobstructed FOV within a zone causes little to no change in accuracy.

Conclusions

The 1ooN coverage for the single flame detector case is below 1% absolute error for all cases tested with zone spacing under 0.25 meters and ray spacing under 1 degree. The error deviation between rotated FOV's is less than 0.5% for all cases tested. The software has therefore PASSED the test.

Case 03: Two Unobstructed FOVs

Summary

This case tests Detect3D's accuracy of 1ooN and 2ooN coverage with two overlapping FOVs within one zone. The variance of accuracy with ray spacing and point cloud is compared against numerical calculations performed in Rhino.

The results show that both the 1ooN and 2ooN coverage error tend to zero as zone spacing decreases, while ray spacing has no effect on coverage accuracy.

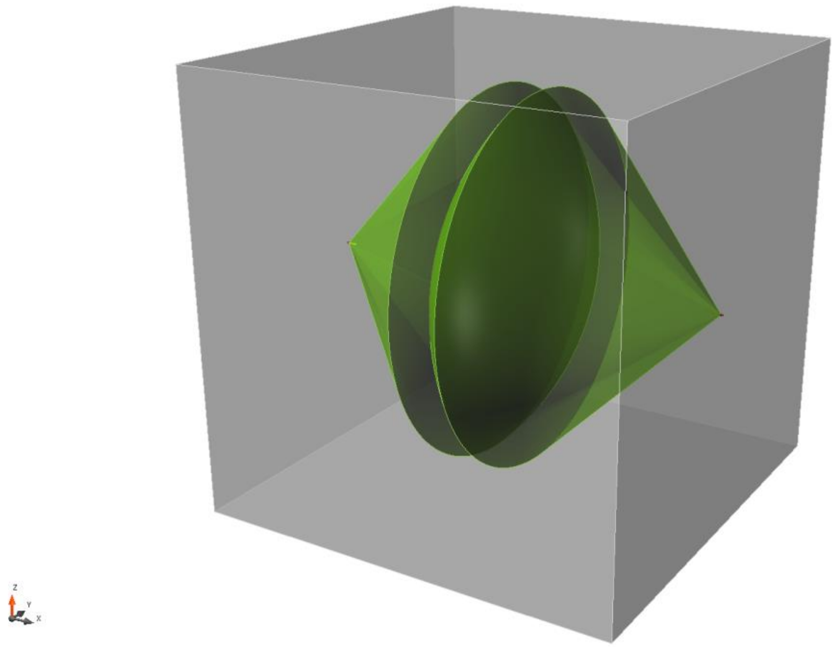

Figure 8: Test case showing two overlapping FOVs.

Public File Locations

…/Flame Detector Mapping/Case 03 – Two Unobstructed FOVs

Pass / Fail Criteria

1% Error margin compared to Rhino results, at 1 degree ray spacing or less, and 0.25 meter point spacing or less.

Results and Discussion

Two FOVs are placed within a zone with some overlap. As in the previous cases, the 1ooN coverage is calculated by the dividing the volume enclosed by at least one FOV by the zone volume as shown in Eq. 9 below. Note that the overlap is subtracted because it is counted in both FOVs.

$$1ooN = \frac{V_{FOV_1} + V_{FOV_2} - V_{overlap}}{V_{zone}} \quad \text{Eq. 9}$$

The 2ooN coverage is similarly calculated by dividing the overlapping volume by the zone volume:

$$2ooN = \frac{V_{overlap}}{V_{zone}} \quad \text{Eq. 10}$$

From the Rhino results, 1ooN coverage is **21.43%** and 2ooN coverage is **5.07%**. The coverage error based on zone spacing and ray spacing is shown below.

Zone Spacing, m	1ooN	2ooN	1ooN Error	2ooN Error
1	20.11%	4.77%	-1.32%	-0.30%
0.5	20.74%	4.91%	-0.69%	-0.16%
0.25	21.11%	4.99%	-0.32%	-0.08%
0.125	21.29%	5.03%	-0.14%	-0.04%

Ray Spacing, degrees	1ooN	2ooN	1ooN Error	2ooN Error
2	21.11%	4.99%	-0.32%	-0.08%
1	21.11%	4.99%	-0.32%	-0.08%
0.5	21.11%	4.99%	-0.32%	-0.08%
0.25	21.11%	4.99%	-0.32%	-0.08%

As expected, the errors tend to zero as the point cloud spacing decreases. Ray spacing has no effect on coverage accuracy with unobstructed FOVs.

Conclusions

The 1ooN and 2ooN coverage for two overlapping FOVs is less than 1% absolute error for all cases tested with zone spacing under 0.25 meters and ray spacing under 1 degree. The software has therefore PASSED the test.

Case 04: Three Unobstructed FOVs

Summary

This case tests Detect3D's accuracy of 1ooN, 2ooN, and 3ooN coverage with three overlapping FOVs. The variance of accuracy with ray spacing and point cloud spacing is compared against numerical calculations performed in Rhino.

The results show the 1ooN, 2ooN, and 3ooN coverage error tend to zero as zone spacing decreases, while ray spacing has no effect on coverage accuracy.

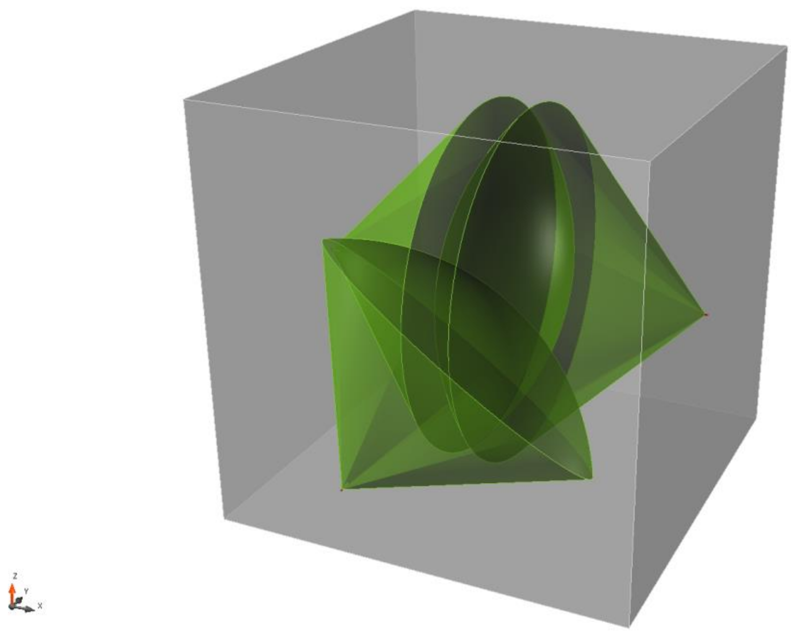

Figure 9: Test case showing three overlapping FOVs in a cuboid zone.

Public File Locations

…/Flame Detector Mapping/Case 04 – Three Unobstructed FOVs

Pass / Fail Criteria

1% Error margin compared to Rhino results, at 1 degree ray spacing or less, and 0.25 meter point spacing or less.

Results and Discussion

Three symmetric FOVs with no bezel are placed fully within the example cuboid zone. As before 1ooN and 2ooN coverages are calculated as shown below.

$$1ooN = \frac{V_{FOV_1} + V_{FOV_2} + V_{FOV_3} - V_{overlap_{2ooN}} - V_{overlap_{3ooN}}}{V_{zone}} \qquad \text{Eq. 11}$$

$$2ooN = \frac{V_{overlap_{2ooN}} - V_{overlap_{3ooN}}}{V_{zone}} \qquad \text{Eq. 12}$$

3ooN coverage is simply the volume enclosed by the overlap of three or more detectors:

$$3ooN = \frac{V_{overlap_{3ooN}}}{V_{zone}} \qquad \textit{Eq. 13}$$

From the Rhino results, 1ooN coverage is **28.21%**, 2ooN coverage is **10.22%**, and 3ooN is **1.69%**. The coverage error based on zone spacing and ray spacing is shown below.

Zone Spacing, m	1ooN	2ooN	3ooN	1ooN Error	2ooN Error	3ooN Error
1	26.14%	9.61%	1.59%	-2.07%	-0.61%	-0.10%
0.5	26.97%	9.89%	1.64%	-1.24%	-0.33%	-0.05%
0.25	27.43%	10.06%	1.67%	-0.78%	-0.16%	-0.02%
0.125	27.65%	10.15%	1.68%	-0.56%	-0.07%	-0.01%

Ray Spacing, degrees	1ooN	2ooN	3ooN	1ooN Error	2ooN Error	3ooN Error
2	27.43%	10.06%	1.67%	-0.78%	0.45%	0.45%
1	27.43%	10.06%	1.67%	-0.78%	0.45%	0.45%
0.5	27.43%	10.06%	1.67%	-0.78%	0.45%	0.45%
0.25	27.43%	10.06%	1.67%	-0.78%	0.45%	0.45%

As expected, the errors tend to zero as the point cloud spacing decreases. Ray spacing has no effect on coverage accuracy with unobstructed FOVs.

Conclusions

The 1ooN, 2ooN, and 3ooN coverage for three overlapping FOVs is less than 1% absolute error for all cases tested with zone spacing under 0.25 meters and ray spacing under 1 degree. The software has therefore PASSED the test.

Case 05: Multiple Overlapping Unobstructed FOVs

Summary

This case tests Detect3D's 1ooN and 2ooN coverage accuracy with multiple overlapping unobstructed FOVs. The variance of accuracy with ray spacing and point cloud spacing is compared against numerical calculations performed in Rhino.

The results show the 1ooN and 2ooN coverage error tend to zero as zone spacing decreases, while ray spacing has no effect on coverage accuracy.

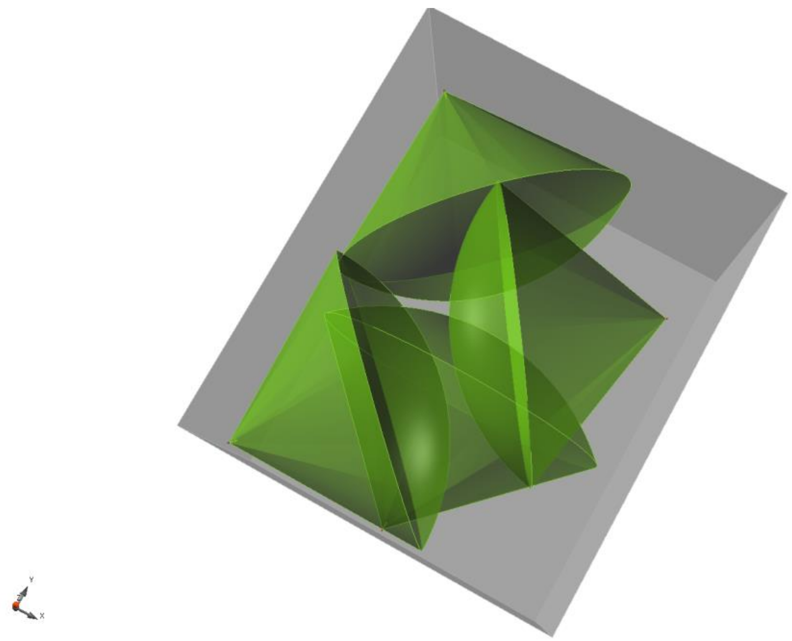

Figure 10: Test case showing multiple unobstructed FOVs.

Public File Location

…/Flame Detector Mapping/Case 05 – Multiple Overlapping Unobstructed FOVs

Pass / Fail Criteria

1% Error margin compared to Rhino results, at 1 degree ray spacing or less, and 0.25 meter point spacing or less.

Results and Discussion

Four symmetric detector FOVs without bezel are placed within a cuboid zone with varying amounts of overlap. The 1ooN coverage can be calculated by dividing the volume with only one FOV coverage by the zone volume, and the 2ooN coverage is the cumulative volume of overlaps divided by the zone volume. Again noting that the overlap volume is counted twice in the summation of FOV volumes, the overlapping regions need to be subtracted in order to obtain the correct coverage.

$$1ooN = \frac{V_{FOV_1} + V_{FOV_2} + V_{FOV_3} + V_{FOV_4} - \sum V_{overlap_{2ooN}}}{V_{zone}} \qquad \textit{Eq. 14}$$

$$2ooN = \frac{\sum V_{overlap_{2ooN}}}{V_{zone}} \qquad \textit{Eq. 15}$$

Numerical calculations within Rhino result in a 1ooN coverage of **35.10%** and a 2ooN coverage of **9.07%**. The Detect3D coverage results and error with respect to zone spacing and ray spacing are given below.

Zone Spacing, m	1ooN	2ooN	1ooN Error	2ooN Error
1	33.08%	8.54%	-2.02%	-0.53%
0.5	34.07%	8.79%	-1.03%	-0.28%
0.25	34.61%	8.94%	-0.49%	-0.13%
0.125	34.87%	9.01%	-0.23%	-0.06%

Ray Spacing, degrees	1ooN	2ooN	1ooN Error	2ooN Error
2	34.61%	8.94%	-0.49%	-0.13%
1	34.61%	8.94%	-0.49%	-0.13%
0.5	34.61%	8.94%	-0.49%	-0.13%
0.25	34.61%	8.94%	-0.49%	-0.13%

Error for both 1ooN and 2ooN coverage tend to zero as zone spacing is decreased, while ray spacing has no effect for unobstructed overlapping FOVs.

Conclusions

The 1ooN and 2ooN coverage for multiple overlapping FOVs is less than 1% absolute error for all cases tested with zone spacing under 0.25 meters and ray spacing under 1 degree. The software has therefore PASSED the test.

Case 06: Single FOV, Single Cylinder Obstruction

Summary

This case tests for accuracy of 1ooN coverage with one FOV and one cylinder obstruction. The variance of accuracy with ray spacing and point cloud spacing is compared against numerical calculations performed in Rhino.

The results show that less than 1% coverage error is achieved with relatively coarse zone and ray spacing, 0.5 meters and 1° respectively.

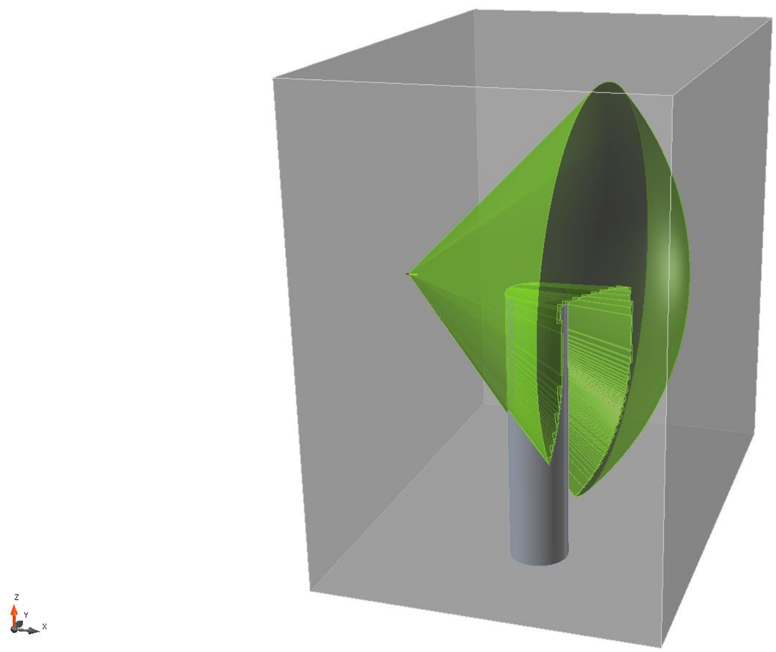

Figure 11: Test case showing a single FOV with a cylinder obstruction.

Public File Location

…/Flame Detector Mapping/Case 06 – Single FOV, Single Cylinder Obstruction

Pass / Fail Criteria

1% absolute error compared to Rhino results, at 1 degree ray spacing or less, and 0.25 meter point spacing or less.

Results and Discussion

In order to calculate the 1ooN coverage with a cylinder obstruction, the projection of the outside edges of the cylinder from the detector origin is created in Rhino. From the projection, a polysurface is created which is then subtracted from the internal volume of the FOV using a Boolean difference. This calculation is shown below.

$$1ooN = \frac{V_{FOV} - V_{projection\ overlap}}{V_{zone}} \qquad \textit{Eq. 16}$$

The Rhino calculations result in a 1ooN coverage of **17.44%**. The Detect3D results with varying zone and ray spacing are shown below.

Zone Spacing, m	1ooN	1ooN Error
1	16.39%	-1.05%
0.5	16.96%	-0.48%
0.25	17.30%	-0.14%
0.125	17.46%	0.02%

Ray Spacing, degrees	Adaptive Refinements	1ooN	1ooN Error
2	0	17.26%	-0.18%
2	1	17.29%	-0.15%
2	2	17.30%	-0.14%
1	2	17.30%	-0.14%
0.5	2	17.30%	-0.14%
0.25	2	17.30%	-0.14%

The results show that adaptive refinements improves accuracy with coarse ray spacing in relation to the complexity of the obstruction. The accuracy increases with a decrease in zone spacing, and the error tolerances are achieved with coarse spacing.

Conclusions

The 1ooN coverage for a single FOV with a single cylinder obstruction is less than 1% absolute error for all cases tested with zone spacing under 0.5 meters and ray spacing under 1 degree. The software has therefore PASSED the test.

Case 07: Single FOV, Multiple Cylinder Obstructions

Summary

This case tests for accuracy of 1ooN coverage with one FOV and multiple cylinder obstructions. The variance of accuracy with ray spacing and point cloud spacing is compared against numerical calculations performed in Rhino.

All zone and ray spacing cases tested resulted in less than 1% absolute error from the numerical solution.

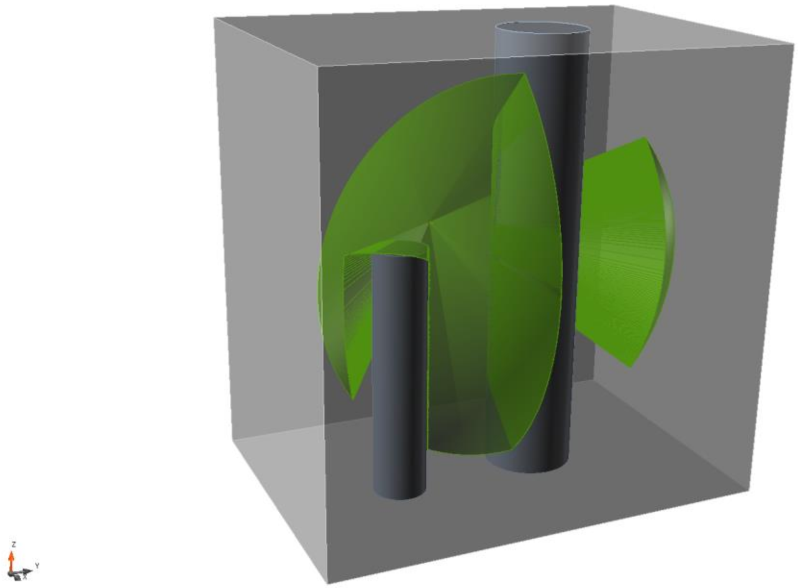

Figure 12: Test case showing a single FOV with multiple cylinder obstructions.

Public File Location

…/Flame Detector Mapping/Case 07 – Single FOV, Multiple Cylinder Obstructions

Pass / Fail Criteria

1% Error margin compared to Rhino results, at 1 degree ray spacing or less, and 0.25 meter point spacing or less.

Results and Discussion

In order to calculate the 1ooN coverage with multiple cylinder obstructions, similar to the previous case, the projection of the outside edges of each cylinder from the detector origin is created in Rhino. From the projection, a polysurface is created which is then subtracted from the internal volume of the FOV using a Boolean difference for each cylinder, shown below.

$$1ooN = \frac{V_{FOV} - \sum V_{projection\ overlap}}{V_{zone}} \qquad \text{Eq. 17}$$

The numerical calculations in Rhino give a 1ooN coverage of **10.53%**. Detect3D results of error with varying point cloud and ray spacing is shown below.

Zone Spacing, m	1ooN	1ooN Error
1	10.43%	-0.10%
0.5	10.73%	0.20%
0.25	10.95%	0.42%
0.125	11.04%	0.51%

Ray Spacing, degrees	Adaptive Refinements	1ooN	1ooN Error
2	0	10.83%	0.30%
2	1	10.91%	0.38%
2	2	10.93%	0.40%
1	2	10.95%	0.42%
0.5	2	10.95%	0.42%
0.25	2	10.95%	0.42%

The results show that adaptive refinements improves accuracy with coarse ray spacing in relation to the complexity of the obstruction. The point cloud spacing for this test case stays within 1% absolute error.

Conclusions

The 1ooN coverage for a single FOV with multiple cylinder obstructions is less than 1% absolute error for all cases tested with zone spacing under 0.5 meters and ray spacing under 1 degree. The software has therefore PASSED the test.

Case 08: Single FOV, Box Obstruction

Summary

This case tests for accuracy of 1ooN coverage with one FOV and one box obstruction. The variance of accuracy with ray spacing and point cloud spacing is compared against numerical calculations performed in Rhino.

All zone and ray spacing cases tested resulted in less than 1% absolute error from the numerical solution.

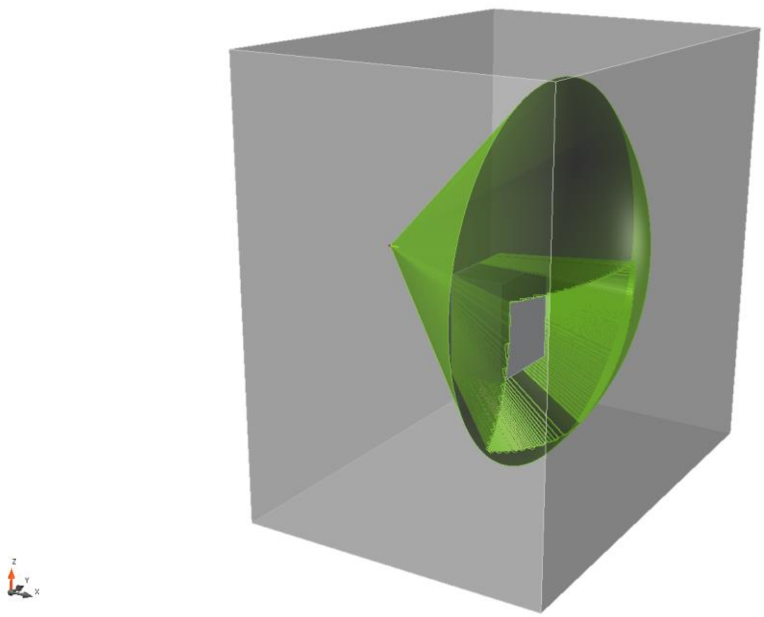

Figure 13: Test case showing a single FOV with a box obstruction.

Public File Location

…/Flame Detector Mapping/Case 08 – Single FOV, Single Box Obstruction

Pass / Fail Criteria

1% Error margin compared to Rhino results, at 1 degree ray spacing or less, and 0.25 meter point spacing or less.

Results and Discussion

In order to calculate the 1ooN coverage with one box obstruction, similar to the previous cases, the projection of the outside edges of the box from the detector origin is created in Rhino. From the projection, a polysurface is created which is then subtracted from the internal volume of the FOV using a Boolean difference, shown below.

$$1ooN = \frac{V_{FOV} - \sum V_{projection\ overlap}}{V_{zone}} \qquad \text{Eq. 18}$$

The numerical calculations in Rhino give a 1ooN coverage of **15.35%**. Detect3D results of error with varying point cloud and ray spacing is shown below.

Zone Spacing, m	1ooN	1ooN Error
1	14.34%	-1.01%
0.5	14.87%	-0.48%
0.25	15.19%	-0.16%
0.125	15.33%	-0.02%

Ray Spacing, degrees	Adaptive Refinements	1ooN	1ooN Error
2	0	15.08%	-0.27%
2	1	15.15%	-0.20%
2	2	15.18%	-0.17%
1	2	15.19%	-0.16%
0.5	2	15.19%	-0.16%
0.25	2	15.19%	-0.16%

The results show that adaptive refinements improves accuracy with coarse ray spacing in relation to the complexity of the obstruction. The point cloud spacing for this test case stays within 1% absolute error for zone spacing less than 1 meter.

Conclusions

The 1ooN coverage for a single FOV with one box obstruction is less than 1% absolute error for all cases tested with zone spacing under 0.5 meters and ray spacing under 1 degree. The software has therefore PASSED the test.

Gas Detection

Case 01: Single Point Gas Detector

Summary

A single point gas detector is placed inside a zone, and the 1ooN coverage is compared against hand calculations. The diameter of the gas cloud evaluated for the coverage is 5 meters. The setup of the test is shown on the figure below.

The results indicate that the absolute error is less than 1% in all cases, and the test is PASSED.

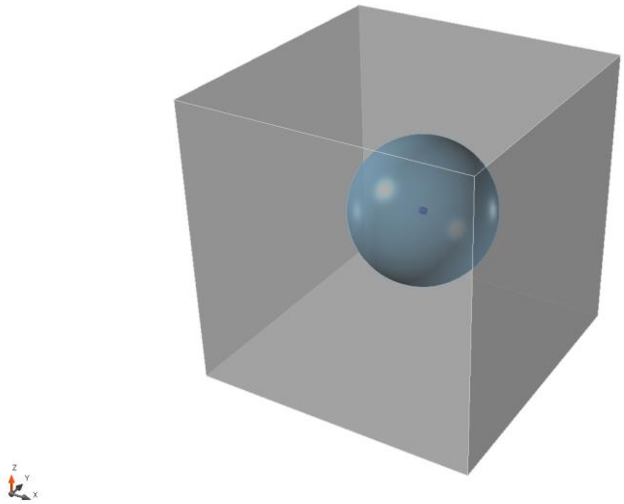

Figure 14. Test case showing point gas detector and its field of influence inside a cube shaped zone.

Public File Locations

../Gas Detector Mapping/ Case 01 - Single Point Gas Detector

Pass / Fail Criteria

Absolute error less than 1% for 1ooN coverage.

Results and Discussion

The field of influence for a point gas detector relative to a gas cloud of diameter D, where the volume of the gas cloud is 100% LEL inside and zero outside the zone, is also a sphere of diameter D. This can be deduced from considering the definition of the field of influence, which is the volume in which the center of the gas cloud must reside for the detector to be in an alarm state.

For example, if the diameter of the gas cloud is 5 meters, then the center of that gas cloud must be within 2.5 meters of the detector for the detector to alarm. In other words, as long as the center of the gas cloud is within a 2.5 meter radius, the detector will alarm. This is equivalent to saying that that the field of influence of the point gas detector is spherical with a radius of 2.5 meters, or diameter of 5 meters.

Based on this argument, it is possible to see that point gas detectors have a spherical field of influence whose diameter is equivalent to the gas cloud under consideration.

Therefore, the 1ooN coverage for a point gas detector in a cubed zone is as follows:

$$1ooN = \frac{V_{sphere}}{V_{cuboid}} = \frac{\pi D^3}{6L^3} \qquad \textit{Eq. 1}$$

where D is the diameter of the gas cloud, and L is the edge length of the zone. In the test case, L = 10 meters and D = 5 meters, resulting in a 1ooN coverage of **6.54%**.

The numerical approximation performed by Detect3D results in the coverage as shown on the table below.

Zone Spacing, meters	1ooN Coverage	Absolute Error
0.25	6.10%	0.44%
0.125	6.33%	0.21%
0.0625	6.44%	0.10%
0.03	6.51%	0.03%

The results indicate that less than 1% absolute error has been achieved for all zone spacing. In addition, the error tends to conservatism – the 1ooN coverage results are less than the exact result in all cases. The error also tends towards zero as the zone spacing is reduced, as expected.

Conclusions

The 1ooN coverage for the single point detector case is below 1% absolute error for all cases tested. The software has therefore PASSED the test.

Case 02: Two Point Gas Detector

Summary

A single point gas detector is placed inside a zone, and the 1ooN coverage is compared against hand calculations. The diameter of the gas cloud evaluated for the coverage is 5 meters. The setup of the test is shown on the figure below.

The results indicate that the absolute error is less than 1% in all cases, and the test is PASSED.

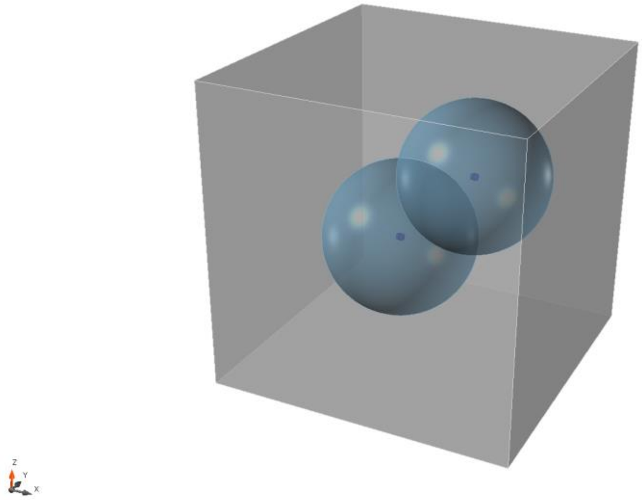

Figure 15. Test case showing two point gas detectors and their fields of influence inside a cube shaped zone.

Public File Locations

../Gas Detector Mapping/ Case 02 - Two Point Gas Detectors

Pass / Fail Criteria

Absolute error less than 1% for 1ooN and 2ooN coverage.

Results and Discussion

As presented in the previous case, the field of influence of a point gas detector is spherical with a diameter equal to the considered gas cloud. The 1ooN and 2ooN coverage for two point gas detectors in close proximity can therefore be calculated based on the geometry of overlapping spheres.

The equation[1] for the volume of two overlapping spheres of equal radius is

$$V_{overlap} = \frac{1}{12}\pi(4R + d)(2R - d)^2 \qquad \textit{Eq. 2}$$

where *R* is the diameter of the sphere (in this case, the radius of the gas cloud) and *d* is the distance between the two spheres. The overlapping volume gives the 2ooN coverage volume, which can then be normalized by the volume of the cuboid zone to give the percentage coverage:

[1] http://mathworld.wolfram.com/Sphere-SphereIntersection.html

$$2ooN = \frac{V_{overlap}}{V_{zone}} \quad \textit{Eq. 3}$$

The 1ooN coverage is simply the volume of the two spheres, with the volume removed:

$$1ooN = \frac{2V_{sphere} - V_{overlap}}{V_{zone}} \quad \textit{Eq. 4}$$

In the test case, R = 2.5 meters, d = 3.03 meters (0.75 meters in the x, y, and z directions) and the zone is a cube of side length 10 meters. Based on these properties, the 1ooN coverage is **11.77%** and the 2ooN coverage is **1.32%**.

The numerical approximation performed by Detect3D results in the coverage as shown on the table below.

Zone Spacing, meters	1ooN Coverage	2ooN Coverage	1ooN Error	2ooN Error
0.25	10.95%	1.23%	0.82%	0.09%
0.125	11.37%	1.28%	0.40%	0.04%
0.0625	11.59%	1.30%	0.18%	0.02%
0.03	11.70%	1.31%	0.07%	0.01%

The results indicate that less than 1% absolute error has been achieved for all zone spacing, for both the 1ooN and 2ooN coverage. In addition, the error tends to conservatism – the coverage results are less than the exact results in all cases. Both errors also tends towards zero as the zone spacing is reduced, as expected.

Conclusions

The 1ooN and 2ooN coverage for the two overlapping point detector test is below 1% absolute error for all cases tested. The software has therefore PASSED the test.

Case 03: Single Open Path Detector

Summary

A single open-path gas detector is placed inside a zone, and the 1ooN coverage is compared against hand calculations. The diameter of the gas cloud evaluated for the coverage is 5 meters. The setup of the test is shown on the figure below.

The results indicate that the absolute error is less than 1% in all cases, and the test is PASSED.

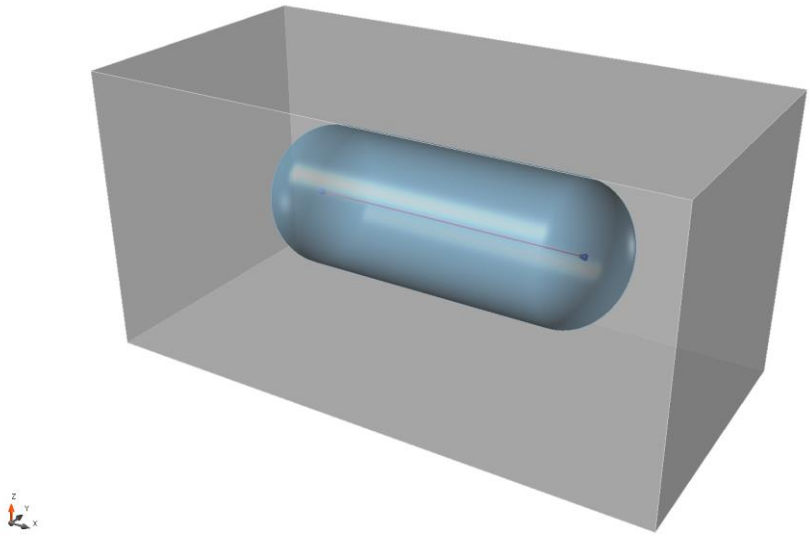

Figure 16. Test case showing the open path gas detector and its field of influence inside a cuboid zone.

Public File Locations

../Gas Detector Mapping/ Case 03 – Single Open Path Gas Detector

Pass / Fail Criteria

Absolute error less than 1% for 1ooN coverage.

Results and Discussion

The field of influence of an open path gas detector is a rounded cylinder. Calculating volume of the rounded cylinder also depends upon the low alarm setting of the point gas detector. Consider half of the profile as shown below:

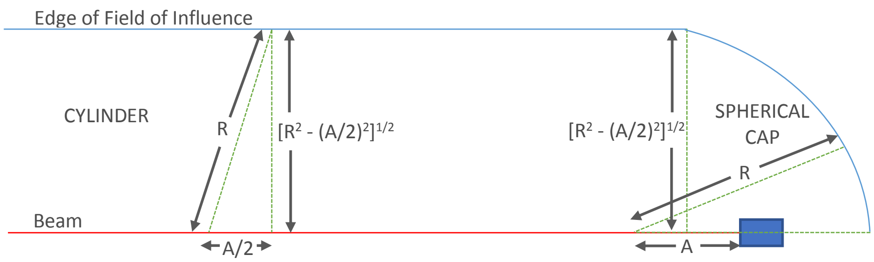

Figure 17. Schematic of the open path detector field of influence.

The profile may be split into two distinct regions – the cylinder and spherical cap.

For the cylinder, the center of the gas cloud must be overlapping at least length A (where A is the length of the low alarm setting i.e. A = 5 meters if the low alarm is 5 LEL.m). This means that the gas cloud must be closer to the beam than the radius of the gas cloud. A simple application of Pythagoras Theorem results in the radius of the cylindrical region, which is $[R^2 - (A/2)^2]^{1/2}$ where R is the radius of the gas cloud.

The spherical region extends between each detector, but not along the entire length of the beam. The maximum extents of the center of the gas cloud can only be valid along a shortened segment of the beam that is a least a distance of A/2 from each detector. If L is the length of the beam, then the volume of the cylinder region must be:

$$V_{cylinder} = \pi r^2 h = \pi(R^2 - (A/2)^2)(L - A) \qquad \textit{Eq. 5}$$

In the region from A/2 to the detector, the condition must be met a least a segment of length A is contained within the spherical gas cloud. For the condition to be true, a spherical cap region of radius R and center A must exist. The volume of one of the spherical cap regions is:

$$V_{cap} = \frac{1}{3}\pi h^2(3r - h) = \frac{1}{3}\pi(R - A/2)^2(2R + A/2) \qquad \textit{Eq. 6}$$

The total volume of the field of influence of the open path detector is then:

$$V_{FOI} = V_{cylinder} + 2V_{cap} \qquad \textit{Eq. 7}$$

In the test case, R = 2.5 meters, A = 1 meter (the low alarm level was 1 LEL.m), L = 10 meters and the zone is a cuboid of dimension 20 x 10 x 10 meters. Based on these properties, the 1ooN coverage is **10.79%**.

The numerical approximation performed by Detect3D results in the coverage as shown on the table below.

Zone Spacing, meters	1ooN Coverage	Absolute Error
0.25	10.18%	0.61%
0.125	10.44%	0.35%
0.0625	10.66%	0.13%
0.03	10.73%	0.06%

The results indicate that less than 1% absolute error has been achieved for all zone spacing. In addition, the error tends to conservatism – the 1ooN coverage results are less than the exact result in all cases. The error also tends towards zero as the zone spacing is reduced, as expected.

Conclusions

The 1ooN coverage for the single open path gas detector case is below 1% absolute error for all cases tested. The software has therefore PASSED the test.

Case 04: Two Open Path Detectors

Summary

Two open-path gas detectors are placed inside a zone, and the 1ooN and 2ooN coverage is compared against hand calculations. The diameter of the gas cloud evaluated for the coverage is 5 meters. The setup of the test is shown on the figure below.

The results indicate that the absolute error is less than 1% in all cases, and the test is PASSED.

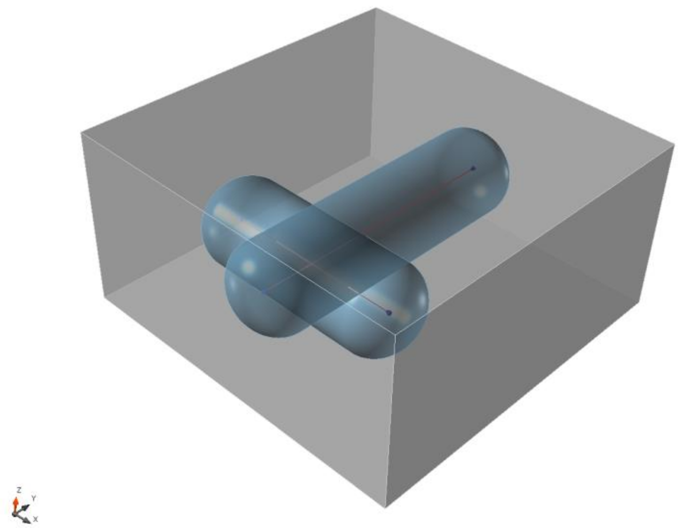

Figure 18. Test case showing two open path gas detector and their fields of influence inside a cuboid zone.

Public File Locations

../Gas Detector Mapping/ Case 04 – Two Open Path Gas Detectors

Pass / Fail Criteria

Absolute error less than 1% for 1ooN and 2ooN coverage.

Results and Discussion

The combined volume of the two open path detectors can be calculated using the formulae presented in the previous test case. As the detectors are perpendicular, at the same height, and overlap in the Cylinder part of the field of influence, the volume of their intersection is a Steinmetz Solid[2] whose volume is simply

$$V_{overlap} = \frac{16}{3} r^3 = \frac{16}{3} \sqrt{(R^2 - (A/2)^2)} \qquad \textit{Eq. 8}$$

In the test case, R = 2.5 meters, A = 1 meter (the low alarm level was 1 LEL.m). The overlapping region, or the 2ooN volume, is therefore 78.38 m^3 in volume.

The length of one detector is 10 meters while the other is 15 meters, resulting in a combined volume of the detectors of 525.69 m^3. This means that the 1ooN volume is 447.31 m^3.

[2] http://mathworld.wolfram.com/SteinmetzSolid.html

The zone is a cuboid of dimension 20 x 20 x 10 meters, resulting in an exact 1ooN coverage of **11.18%** and a 2ooN coverage of **1.96%**.

The numerical approximation performed by Detect3D results in the coverage as shown on the table below.

Zone Spacing, meters	1ooN Coverage	2ooN Coverage	1ooN Error	2ooN Error
0.25	10.69%	1.86%	0.49%	0.10%
0.125	10.90%	1.90%	0.28%	0.06%
0.0625	11.08%	1.94%	0.10%	0.02%
0.03	11.14%	1.95%	0.04%	0.01%

The results indicate that less than 1% absolute error has been achieved for all zone spacing. In addition, the error tends to conservatism – the 1ooN and 2ooN coverage results are less than the exact result in all cases. The error also tends towards zero as the zone spacing is reduced, as expected.

Conclusions

The 1ooN coverage for the single open path gas detector case is below 1% absolute error for all cases tested. The software has therefore PASSED the test.

Case 05: Overlapping Point and Open Path Detectors

Summary

Two open-path gas detectors are placed inside a zone, together with 6 point gas detectors. The 1ooN and 2ooN coverage is compared against hand calculations. The diameter of the gas cloud evaluated for the coverage is 5 meters. The setup of the test is shown on the figure below.

The results indicate that the absolute error is less than 1% in all cases, and the test is PASSED.

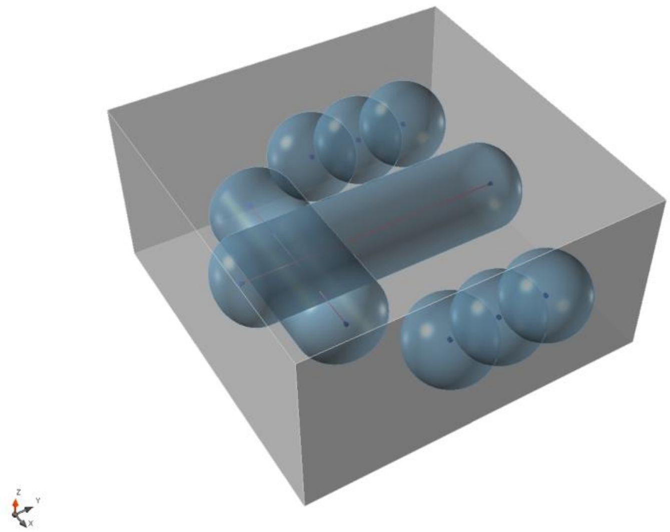

Figure 19. Test case showing multiple point and open path gas detectors inside a cuboid zone.

Public File Locations

../Gas Detector Mapping/ Case 05 - Overlapping Point and Open Path Detectors

Pass / Fail Criteria

Absolute error less than 1% for 1ooN and 2ooN coverage.

Results and Discussion

The setup of the open path gas detectors exactly mirrors the previous case, so the 1ooN volume is 447.31 m^3 and the 2ooN volume is 78.38 m^3 considering just the open path detectors alone.

The point gas detectors are all 3 meters apart. The combined volume of the point gas detectors is 392.70 m^3, and the four overlapping regions all have 13.61 m^3 volume for a total of 54.45 m^3. The 1ooN volume for the point gas detectors is therefore 338.24 m^3.

The total 1ooN volume is therefore 785.55 m^3 and the 2ooN volume is 132.84 m^3. The zone is a cuboid of dimension 20 x 20 x 10 meters, resulting in an exact 1ooN coverage of **19.64%** and a 2ooN coverage of **3.32%**. The numerical approximation performed by Detect3D results in the coverage as shown on the table below.

Zone Spacing, meters	1ooN Coverage	2ooN Coverage	1ooN Error	2ooN Error
0.25	18.68%	3.14%	0.96%	0.18%
0.125	19.14%	3.23%	0.50%	0.09%
0.0625	19.45%	3.29%	0.19%	0.03%
0.03	19.56%	3.30%	0.08%	0.02%

The results indicate that less than 1% absolute error has been achieved for all zone spacing. In addition, the error tends to conservatism – the 1ooN and 2ooN coverage results are less than the exact result in all cases. The error also tends towards zero as the zone spacing is reduced, as expected.

Conclusions

The 1ooN and 2ooN coverage for the multiple overlapping point and open path gas detector case is below 1% absolute error for all cases tested. The software has therefore PASSED the test.

Internal Volume Calculation

Case 01: Single Box

Summary

A box was placed inside a cuboid zone. The external volume calculation is compared against hand calculations. Note that the external volume is used to normalize the coverage calculations.

The results indicate that the relative error is less than 1% in all cases, and the test is PASSED.

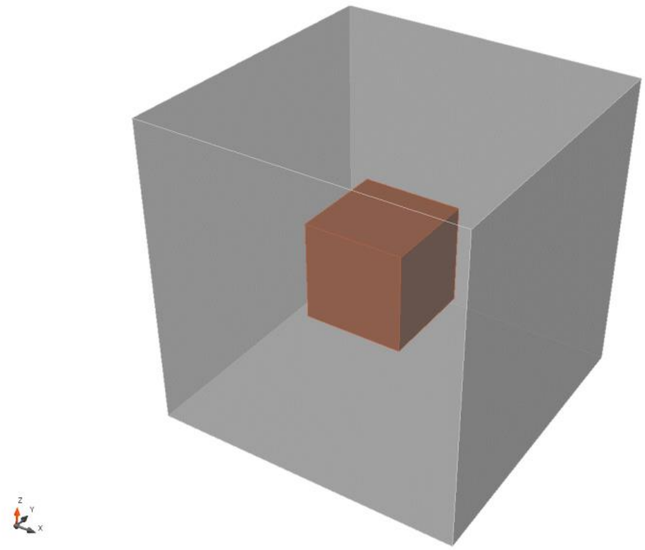

Figure 20. Test case showing the box inside a cuboid zone.

Public File Locations

../Internal Volume Calculation/ Case 01 – Single Box

Pass / Fail Criteria

Relative error less than 1% for external volume.

Results and Discussion

The box is a cube of length 3.2 meters, resulting in a volume of 32.3 m^3. The box is fully contained within a zone of 10 m^3, so the external volume is **967.23 m^3**.

The numerical approximation performed by Detect3D results in the coverage as shown on the table below.

Zone Spacing, meters	External Volume, m^3	Relative Error
0.25	968.12	0.09%
0.125	966.93	-0.03%
0.0625	968.21	0.10%
0.03	967.57	0.03%

The results indicate that less than 1% relative error has been achieved for all zone spacings. The results do not indicate any preference for over- or under-prediction of the external volume in this case. The error may also not tend to zero as zone spacing is decreased.

Conclusions

The external volume was correctly calculated within 1% relative error for the box case. The software has therefore PASSED the test.

Case 02: Single Cylinder

Summary

A cylinder was placed inside a cuboid zone. The external volume calculation is compared against hand calculations. Note that the external volume is used to normalize the coverage calculations.

The results indicate that the relative error is less than 1% in all cases, and the test is PASSED.

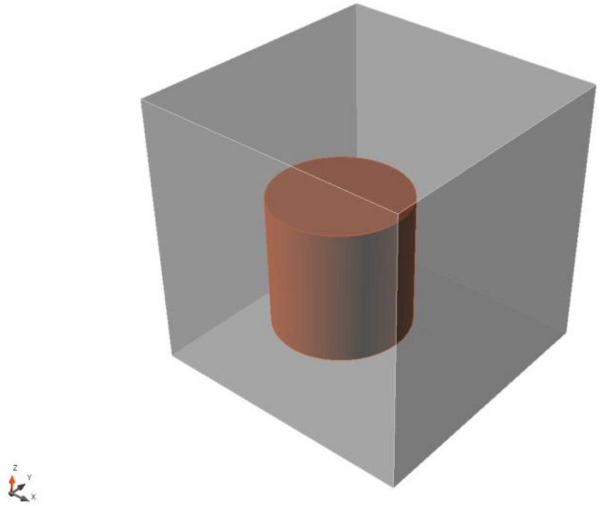

Figure 21. Test case showing the cylinder inside a cuboid zone.

Public File Locations

../Internal Volume Calculation/ Case 02 – Single Cylinder

Pass / Fail Criteria

Relative error less than 1% for external volume.

Results and Discussion

The cylinder has a radius of 2.5 meters and a height of 5 meters, resulting in a volume of 98.2 m^3. The box is fully contained within a zone of volume 1,000 m^3, so the external volume is **901.83 m^3**.

The numerical approximation performed by Detect3D results in the coverage as shown on the table below.

Zone Spacing, meters	External Volume, m^3	Relative Error
0.25	909.17	0.81%
0.125	905.69	0.43%
0.0625	904.00	0.24%
0.03	902.68	0.09%

The results indicate that less than 1% relative error has been achieved for all zone spacings. The results do not indicate that the external volume is generally over-predicted. This is a conservative error, as greater external volume will tend to reduce the coverage results. The error also tends to zero as the zone spacing reduces, as expected.

Conclusions

The external volume was correctly calculated within 1% relative error for the single cylinder case. The software has therefore PASSED the test.

Case 03: Multiple Cylinders

Summary

Six cylinders were placed inside a cuboid zone. The external volume calculation is compared against hand calculations. Note that the external volume is used to normalize the coverage calculations.

The results indicate that the relative error is less than 1% in all cases, and the test is PASSED.

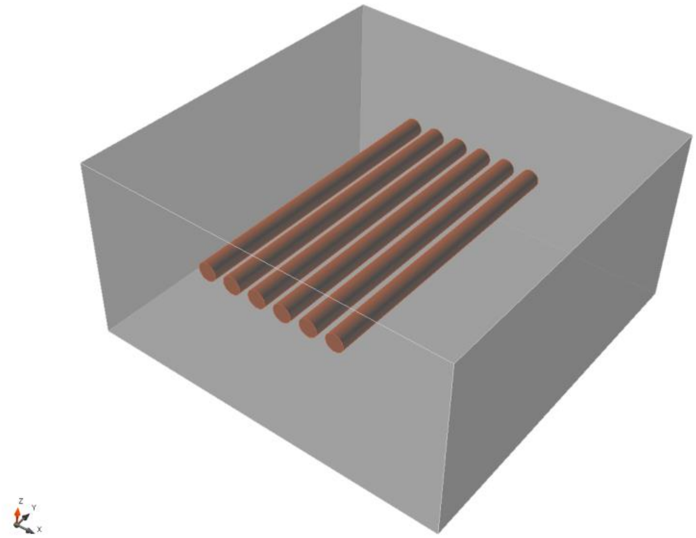

Figure 22. Test case showing the multiple cylinders inside a cuboid zone.

Public File Locations

../Internal Volume Calculation/ Case 03 – Multiple Cylinders

Pass / Fail Criteria

Relative error less than 1% for external volume.

Results and Discussion

The cylinders each have a radius of 0.5 meters and a length of 16 meters, resulting in a combined volume of 75.4 m^3. The box is fully contained within a zone of volume 4,000 m^3, so the external volume is **3924.6 m^3**.

The numerical approximation performed by Detect3D results in the coverage as shown on the table below.

Zone Spacing, meters	External Volume, m^3	Relative Error
0.25	3931.48	0.18%
0.125	3931.23	0.17%
0.0625	3925.93	0.03%
0.03	3925.16	0.01%

The results indicate that less than 1% relative error has been achieved for all zone spacings. The results do not indicate that the external volume is generally over-predicted. This is a conservative error, as greater external volume will tend to reduce the coverage results. The error also tends to zero as the zone spacing reduces, as expected.

Conclusions

The external volume was correctly calculated within 1% relative error for the multiple cylinder case. The software has therefore PASSED the test.

Case 04: Complex Volume

Summary

A complex shape (knot) was placed inside a cuboid zone. The external volume calculation is compared against numerical calculations performed in Rhino. Note that the external volume is used to normalize the coverage calculations.

The results indicate that the relative error is less than 1% in all cases, and the test is PASSED.

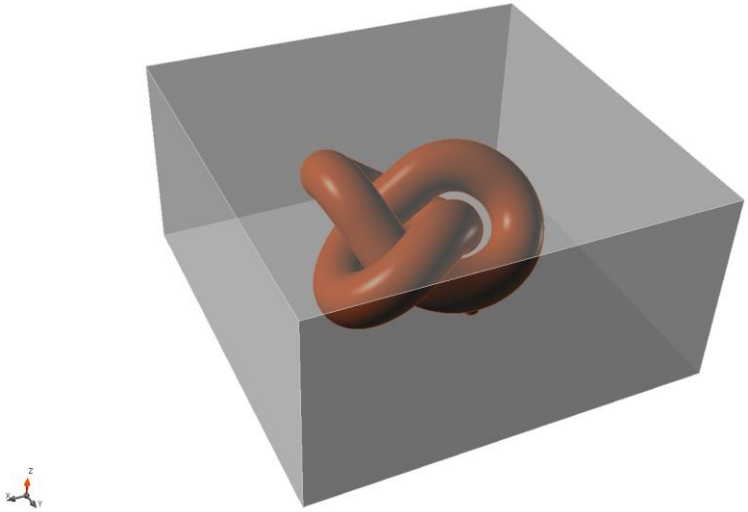

Figure 23. Test case showing the complex knot shape inside a cuboid zone.

Public File Locations

../Internal Volume Calculation/ Case 04 – Complex Shape

Pass / Fail Criteria

Relative error less than 1% for external volume.

Results and Discussion

The volume of the knot calculated by Rhino is 254.15 m^3. The box is fully contained within a zone of volume 4,000 m^3, so the external volume is **3745.85 m^3**.

The numerical approximation performed by Detect3D results in the coverage as shown on the table below.

Zone Spacing, meters	External Volume, m^3	Relative Error
0.25	3758.08	0.33%
0.125	3751.76	0.16%
0.0625	3748.49	0.07%
0.03	3746.86	0.03%

The results indicate that less than 1% relative error has been achieved for all zone spacings. The results do not indicate that the external volume is generally over-predicted. This is a conservative error, as greater external volume will tend to reduce the coverage results. The error also tends to zero as the zone spacing reduces, as expected.

Conclusions

The external volume was correctly calculated within 1% relative error for the complex shape case. The software has therefore PASSED the test.

Overall Conclusions

A series of test cases have been defined for the fire and gas mapping software Detect3D. In all cases, the coverage given by Detect3D has been compared to hand calculations, or numerical calculations. Pass/fail criteria has typically been set to 1% absolute error for coverage.

Detect3D has been shown to be highly accurate, calculating coverage within 1% absolute error for all cases test at the recommended settings.

The default settings in Detect3D of 0.25 meters for zone spacing, and 1° resolution with 2 adaptive refinements for flame detectors, have been shown to result in an absolute error of less than 1% in all test cases.

These conclusions are limited only to the test cases in the report. Sensitivity studies for the zone resolution and flame detector ray casting resolution should always be carried out for projects using Detect3D.